VERSITA

Environmental and Climate Technologies

doi: 10.2478/v10145-012-0023-9

2012 / 10

Industrial Research of Condensing Unit for Natural Gas Boiler House

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Abstract **– In the course of work industrial research was carried out at the boiler plant A/S "Imanta" where a 10MW passive condensing economizer working on natural gas was installed after the 116MW water boiler. The work describes the design of the condensing economizer and wiring diagram. During the industrial experiment, the following measurements were made: the temperature of water before and after the economizer; the ambient temperature; the quantity of water passing through the economizer; heat, produced by the economizer and water boilers. The work summarizes the data from 2010-2011.**

Keywords **– condensing economizer, energy efficient, latent heat, flue gas**

I. Introduction

Each EU member state has to reach energy and climate target in 2020 by improving energy efficiency and increasing use of renewable energy [4; 5].

The rate at which energy efficiency questions are solved in Latvia has significantly increased in recent years. Nowadays, it is impossible to make, technological progress without improvements in energy efficiency, due to the limited fossil fuel recourses. The energy efficient technological solutions available today allow the economically reasonable use of energy resources. One of the most important aspects of energy and ecoefficient solutions is compliance of environment protection requirements. Consequently, the main tasks for the energy industry are the reduction of energy consumption and increase in energy efficiency. In light of this, energy utilities and district heating companies more and more apply new measures to improve energy efficiency. One of the key measures to improve energy efficiency of existing boilers is through the utilization of flue gas heat.

The experience, presented in this article, is obtained in district heating boiler houses fuelled by natural gas [3]. Analysis of data of the flue gas condensing unit in the boiler house and the results of industrial research work are carried out with the 10 MW condensing economizer, installed behind the natural gas fuelled 116 MW water heating boiler KVGM 100 in A/S "Imanta".

II. Industrial Experiment Description

The condensing economizer is a classic tubular heat exchanger used for heat transmission from hot heat-transfer agent (flue gas) to cool (heating network water) [2]. Economizer is cross-flow a heat exchanger by the heat agents flow direction aspect. The economizer consists of four equal sections; each section consists of six standard modules. To increase heat exchange efficiency, tubes in beam are connected to the horizontal plates, which create an angular tube effect.

The economizer is installed in the boiler KVGM-100 flue gas channel and is placed between the fan and chimney. The boiler can work when the economizer is unlocked by use of by-pass line. Return water from the district heating (DH) network is used as a heat-exchange agent in the economizer. The circulating water is heated up by absorbing physical and condensing heat energy, and returns in the return line of the DH system network water collector. The flue gas cooling process releases:

- physical heat – flue gas enthalpy difference between the flue gas entrance temperature of 160-180 $^{\circ}$C and the outlet temperature 40-50 $^{\circ}$C,
- condensation heat – heat that is released in the process of water vapour cooling when steam temperature is lower than dew point (lower than 57-58 $^{\circ}$C).

The framework of the industrial experiment (see Figure 1) includes a number of measurements which are illustrated in Table I. The most important of them are the temperatures: network water temperature before and after the condensing unit; flue gas temperatures before and after condensing unit.

TABLE I
INDUSTRIAL RESEARCH DATA

Parameter	Measurement unit	The measuring range	Designation scheme
Temperature before the economizer	^{0o}C	36.8 – 55.9	T_2
Temperature after the economizer	^{0o}C	41.2 – 58.6	T_2'
Flue gas temperature before the economizer	^{o0}C	68.1 – 127.0	T_3
Outdoor air temperature (the average daily)	^{0o}C	(-20.3) – (+21.1)	$T_{āra}$
Economizer heat production (per month)	MWh	410 - 4400	Q_{eko}

The amount of produced heat energy in the economizer is measured by the heat meter. Water flow in all sections of the economizer is divided equally, because all four sections are in parallel connection and have equal hydraulic resistance.

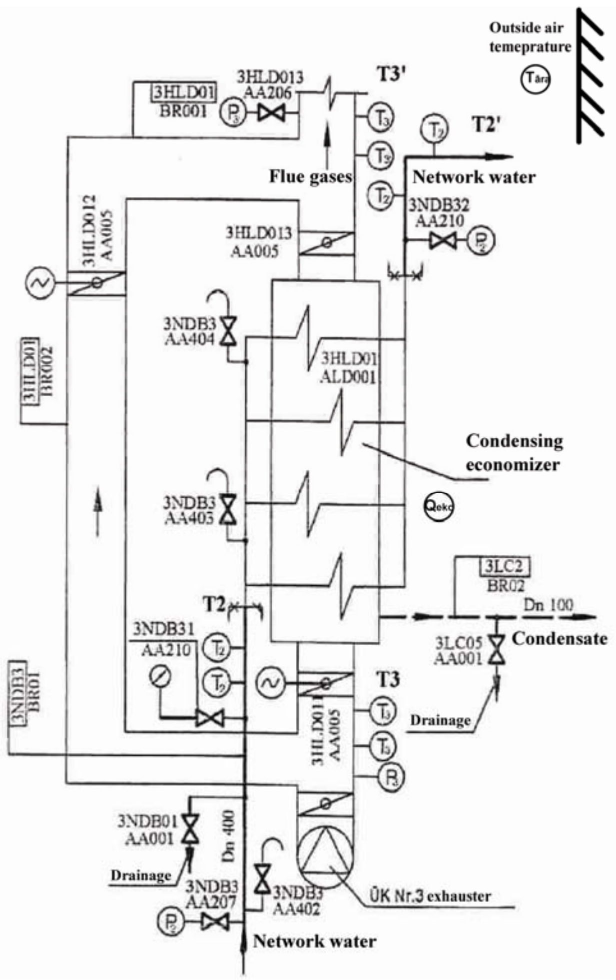

Fig. 1. Parameter measurement scheme for condensation economizer

T2 – return network water temperature before the economizer;

T2' – network water temperature after the economizer;

T3 – flue gas temperature before the economizer;

T3'- flue gas temperature after the economizer;

$T_{\bar{a}ra}$ – outdoor air temperature;

Q_{eko} – heat production of the economizers

As a result of flue gas vapour cooling, condensate appears and drifts into a 3 m^3 condensate collector tank. When the condensate reaches mid-level of the tank one of two condensate pumps turns on automatically.

The condensate pump of the collector tank pumps condensate in a large 20 m^3 condensate collection container. Condensate has 3.5-6 pH (acidic).

Within the industrial research process the following measurements (Figure 1) were performed: the amount of heat produced by water heating boilers, consumed natural gas, outdoor air temperature (daily average), flue gas temperature T3 before and T3' after economizer. The research includes processing of average monthly data for years 2010 and 2011 as well as daily data for the months summarized.

Experimental data are presented in Figure 2 as an example. They illustrate changes in parameters of the economizer operation during one month: in January 2010. It shows a link between the DH system return water temperature, condensing unit heat production and outdoor temperature.

Data shows links among three parameters and the impact of temperatures on the capacity of the condensing unit.

Similar graphs are available for other measurement data. This allows one to conclude that there is a continue data processing and empirical modelling.

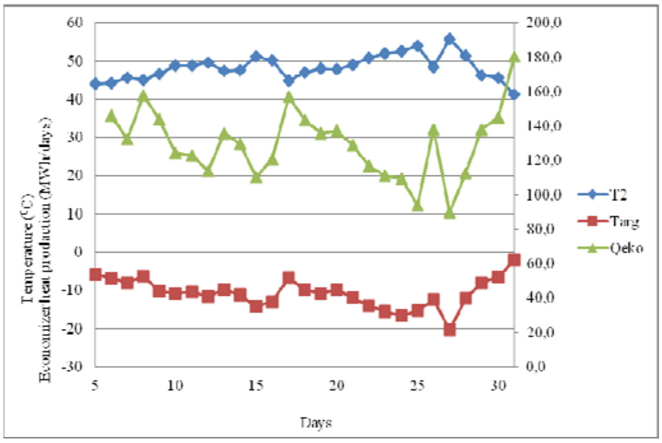

Fig. 2. Condensing economizer operation in January 2010

III. Regression Analysis of Data

The aim of data statistical processing is to find graphical or analytical correlation between variables. The found analytical expression is called regression equation of process (mathematical model). Regression analysis designates random variable changes in precise quantitative parameters – importance of stochastic links expressed with functional correlation. As a result of regression analysis it is possible to obtain quantitative parameters for statistical correlation closeness of the independent and dependent random variables and determine regression coefficients [1].

In general, the capacity of the condensing unit depends on multiply parameters: the amount and temperature of the flue gas before the economizer, the return network water temperature and quantity, condensing economizer surface size and material.

The capacity of the condensing unit depends on outdoor temperature: decrease of outdoor temperature creates a need for higher capacity of condensing unit. The empirical model of capacity of condensing unit versus outdoor temperature (see Figure 3) is expressed in the form of a linear regression equation and shows good correlation between data and model:

$$Q_{eko} = -130.29 t_{arg} + 3355.7 \quad (1)$$

where

Q_{eko} – capacity of condensing unit, MWh;

t_{arg} - outdoor temperature, $^{\circ}$C.

Processed data set m=17. The selected significance level value P is 0.05. Determine degree of freedom: f = m – (n +

1) = 17 – (1 +1) =15. With these values criterion t found in Student's distribution tables is ttab = 2.13. This means that the estimated coefficients have to be within the borders │t│> ttab. With the help of computer programme criteria t are calculated. Selected value of significance P = 0.05, agree with probability of reliability 1 – P = 0.95.

As shown in Table II, relevance │t│> ttab is valid in all cases. This means that all the parameters are significant and must be maintained in an equation. The performed analysis shows that the value of R2 is 0.7545 and the correlation coefficient is 0.87. Correlation coefficient indicates a close link between the economizer production of heat and outdoor temperature. Created model explains 75.5 % of analyzed heat produced by economizers. To increase the effectiveness of the economizer's work, the linear line has to be above the one that was established on data from the industrial experiment.

TABLE II
THE ESTIMATION OF REGRESSION PARAMETERS

Parameters (equation)	Value	t criterion (t-test)	P value
Constant b_o (1.1)	3355.72	16.0028	0.0000
Coefficient b_1 (1.1)	-130.292	-6.78892	0.0000
Constant b_o (1.2)	39.4849	90.9846	0.0000
Coefficient b_1 (1.2)	-0.818307	-20.9783	0.0000
Constant b_o (1.3)	0.0870769	41.4784	0.0000
Coefficient b_1 (1.3)	0.0024339	13.2245	0.0000
Constant b_0 (1.4)	0.203	30.2484	0.0000
Coefficient b_1 (1.4)	-0.0029	-21.2135	0.0000

As shown in Figure 3, in 6 of 17 cases, the results are above average. Modelling of capacity of condensing unit starts from these points, by use of dissipation results. Characteristics for more effective work of condensing unit present several linear equations on the basis on these data (see Figure 4). At minimum outdoor temperature lines come together, because the work of economizer reaches it's maximum. At higher outdoor temperatures, the economizer's efficiency depends on several parameters and the heat production curve follows one of the multiple lines above the one obtained in the experiment.

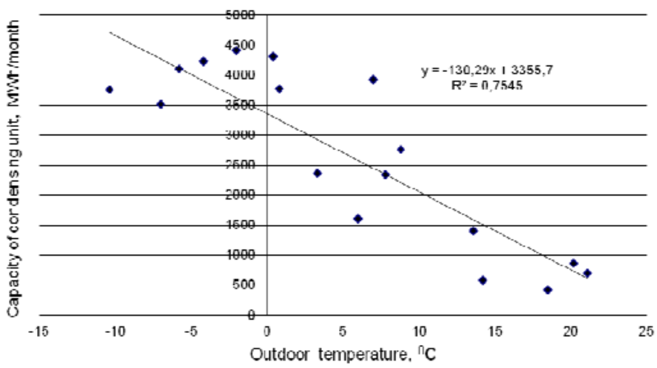

Fig. 3. Capacity of condensing unit versus outdoor temperature

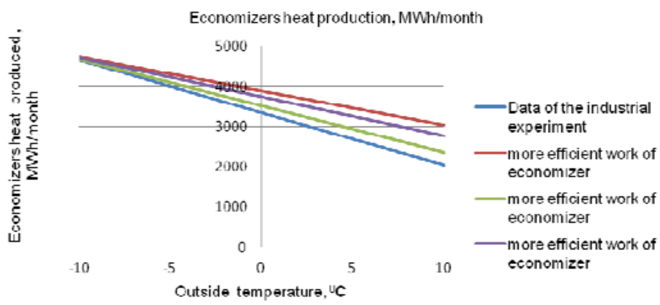

Fig. 4. Modelling of capacity of condensing unit versus outdoor temperature

Other correlations are found between return water temperature versus outdoor temperature and confirms partly qualitative control of DH system. When parameters obtained in the coldest month are expressed separately, it is possible to conclude that with decreasing outdoor temperature, the network's return water temperature increases (Figure 5).

The correlation is expressed in the form of a linear regression equation.

$$t_2 = -0.8183 t_{arg} + 39.485 \quad (2)$$

where

t_2 – water temperature of the return network, °C;

t_{arg}- outdoor air temperature, °C.

Processed data set m=31. Selected significance levels P value is 0.05. Determined degree of freedom: f = m – (n + 1) = 31 – (1 +1) =29. With these values criterion t found in Student's distribution tables is ttab = 2.0452. This means that the estimated coefficients have to be within the borders │t│> ttab. On the basis of data in Table I, relevance │t│> ttab is valid in all cases. This means that all parameters are significant and must be maintained in the equation. The performed analysis shows that the value of R2 is 0.9382. The created empirical model (2) explains 93.82% of analyzed return water temperatures. Graphical correlation shows that decreasing outdoor temperature increases water temperature in return network.

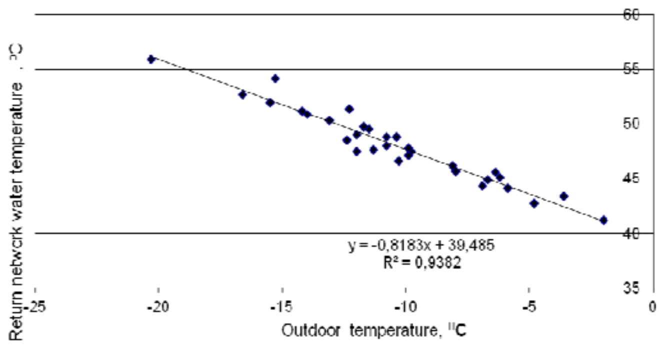

Fig. 5. Return network water temperature versus outdoor temperature.

Other correlations are found between specific capacity of condensing unit versus outdoor temperature and confirms good correlation between data and empirical model.

Specific capacity is indicator which shows share of heat production of condensing unit in relation to the boiler. Increase of outdoor temperature creates increase of specific energy production in condensing unit (see Figure 6).

Specific capacity dependence from the outdoor temperature is characterized by a linear regression equation:

$$q_{eko} = 0.0024\, t_{arg} + 0.087 \quad (3)$$

where

q_{eko} - specific productivity of economizer, -;

t_{arg} - outdoor air temperature, °C.

Another correlation is found between specific capacity of condensing unit versus return water temperature and confirms good correlation between data and empirical model. Specific capacity of condensing unit decreases with increasing return water temperature (see Figure 7). The process is characterized by a linear regression equation:

$$q_{eko} = -0.0029\, t_2 + 0.203 \quad (4)$$

where

q_{eko} - specific productivity of economizer, -;

t_2 – return water temperature, °C.

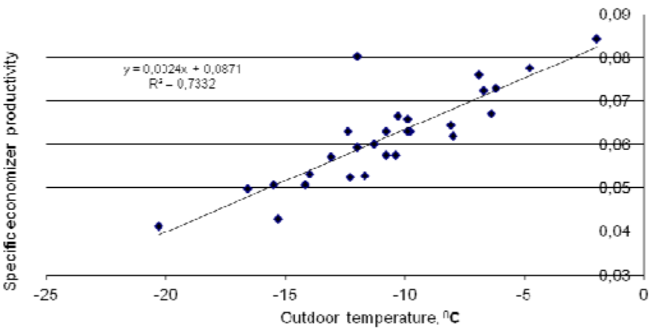

Fig. 6. Specific capacity of condensing unit versus outdoor temperature

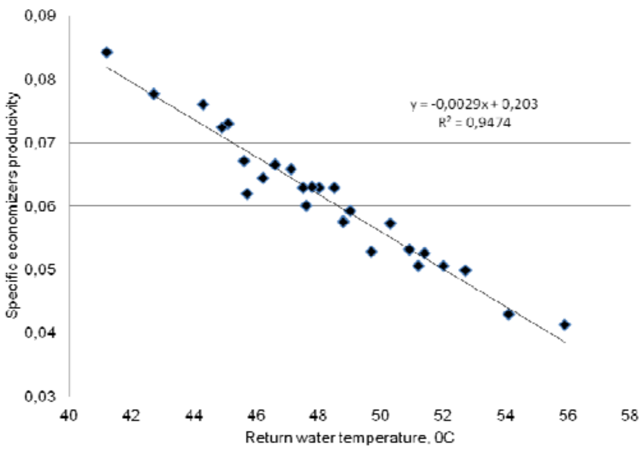

Fig.7. Specific economizer productivity in relation to return water temperature

Exploitation data analyze discovered that minimum temperature of water in heat source return network during the heating season can reach 38 ºC.

A dissipation modelling approach is possible to use in the case of dependence of specific capacity of condensing unit from return water temperature and outdoor temperature. Models within which return water temperature is reduced to 38 ºC with outdoor temperature 0 ºC were constructed in Figure 8. Several models characterize the effective work of economizer when outdoor temperature is decreasing. Within all reviewed models, the return water temperature is lower compared to data from the industrial experiment. This allows to increase the specific productivity of economizer in models (see Figure 8).

Model data (Figure 9) shows, that the maximal amount of heat produced by economizer to the amount of heat produced by boiler, ratio is 0.092. This result is achieved with a boiler heat load of 92 MW and an economizer heat load of 8.5 MW. Those are the most efficient operating parameters. 92 MW represents 80% of the maximum boiler heat load.

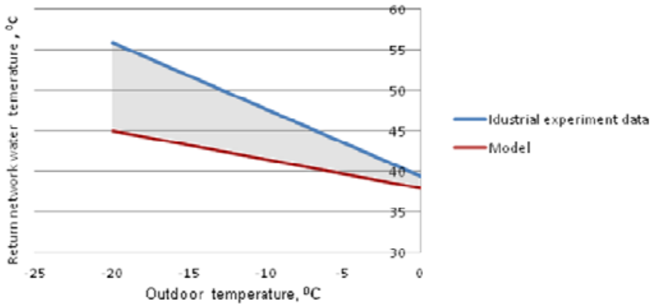

Fig. 8. Return network water temperature in relation to outdoor temperature

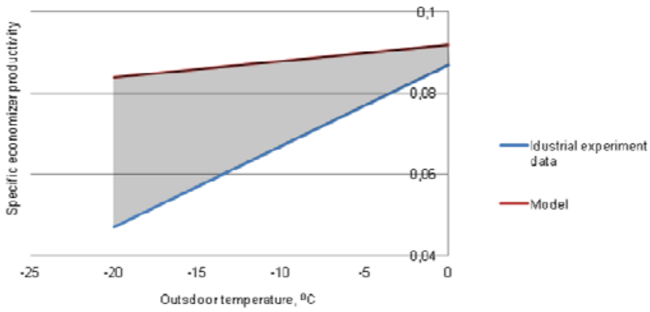

Fig. 9. Specific economizer productivity in relation to outdoor temperature

IV. Conclusions

1. The considerable increase of the return network water temperature according to graphic of heat supply network temperature is the factor that restricts the latent heat output at low outdoor temperature. If return network water temperature is higher than 52 ºC , the economizer stops functioning in condensation mode and heat production decreases by 43%, in comparison to the mode where the temperature is 42 ºC
2. The most efficient operating mode of the economizer, as it was established during the experiment, is that with the

boiler load 92 MW, which is close to nominal, and economizer load accordingly 8.5 MW. This boiler operating mode provides the highest flue gas temperature that gives the biggest temperature gap between flue gas and return water. This has to be taken into account when choosing exploitation mode of boiler house.

3. Use of condensing economizers allows to save 5.4 million nm^3 of fossil fuels and reduce carbon dioxide emissions by 10290 tons or 7% during the period from January 2010 to December 2011.
4. Making a single investment in a facility (condensing economizer), company can obtain heat energy without additional use of energy recourses for years. Investments in this type of assets allow a company to recover them in a very short time. The project payback period is 2-3 years.

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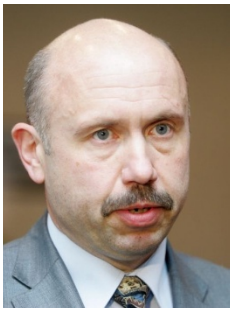

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